Neutrinos And Cosmic Rays From Gamma Ray Bursts

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The upper limit on the flux of ultra high energy neutrinos from γ-ray bursts (GRBs) reported recently by the IceCube collaboration contradicts predictions based on the Fireball model of GRBs, but does not exclude GRBs as a main source of ultra-high energy cosmic rays.

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In a recent letter published in Nature[1], the IceCube collaboration reported an experimental upper limit on the flux of ultra-high energy (energies above EeV$= 10^{18}$ electronvolts) neutrinos from γ-ray bursts (GRBs) that is at least a factor of 3.7 below theoretical predictions[2,3,4] based on the fireball model of GRBs. Hence, they concluded that GRBs are not the only source of ultra-high energy (UHE) cosmic rays or the efficiency of UHE neutrino production is much lower than that predicted. However, while presenting important experimental results, the IceCube collaboration has over-interpreted their results.

The fireball model of GRBs that was used to predict the expected fluxes of ultra-high energy cosmic rays and neutrinos[2,3,4] from GRBs, has already been challenged by many observations of GRBs and their afterglows[5]. Neutrino flux estimates based on this model cannot be relied on in drawing any conclusions either on cosmic ray acceleration to ultra-high energy in GRBs or on the production of UHE neutrinos in GRBs. In particular, alternative estimates of the fluxes of UHE cosmic rays and neutrinos from GRBs[6] that were based on the cannonball model of GRBs, which, so far, was shown to reproduce well the observed properties of GRBs and their afterglows[7,8], have yielded neutrino fluxes that are much smaller than the upper limit obtained by the IceCube collaboration[1].

Moreover, recent studies with the Pierre Auger Observatory (PAO) of the nuclear mass composition of ultra-high energy cosmic rays that reach Earth indicate that their composition changes gradually between 4 EeV and 40 EeV from proton-dominated composition to iron-dominated composition[9] (provided that standard high energy particle physics is still valid at ultra-high energies). The production of neutrinos with ultra-high energy E requires accelelaration in GRB fireballs of protons and/or other atomic nuclei of mass number A to energies $\gtrsim 10\,A\,E$. But complex nuclei cannot be accelerated in the alleged GRB fireballs to such ultra-high energies because they disintegrate in collisions with fireball photons long before they reach these ultra-high energies.

The flux of UHE extragalactic cosmic ray nuclei is strongly reduced by photo-disintegration in collisions with photons of the cosmic infra-red and microwave background radiation[6,10]. Hence, if the PAO composition is correct[11] then extragalactic sources, including extragalactic GRBs, cannot be the main source of the UHE cosmic ray nuclei observed in the Galaxy, and[12]: (a) the 'ankle' near 4 EeV in the energy spectrum of Galactic cosmic rays most probably is the energy beyond which the deflections of CR protons and He4 nuclei in the Galactic magnetic fields can no longer isotropise them nor prolong significantly their escape from the Galaxy, and (b) the spectral break near 50 EeV observed by the Fly's Eye High Resolution (HiRes) experiment[13] and by PAO[14] may be the 'escape-break' of ultra-high energy iron nuclei from the Galaxy, whose energy is $Z/2 = 13$ times higher than that of the helium escape-break rather than the so called 'GZK cutoff' - the effective threshold for energy losses of cosmic ray protons by pion production in collisions with the cosmic microwave background (CMB) radiation. These losses exponentially suppress the extragalactic fluxes of cosmic rays beyond $\sim 50\,A$ EeV, as noted by Greisen[15] and by Zatsepin and Kuzmin[16] in 1966 right after the discovery of the CMB.

Galactic GRBs, most of which, mercifully[17], are beamed away from Earth, can be the main source of Galactic cosmic rays at all energies[12,18].

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